Aleutian Islands Pacific cod assessment models September 2021

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Introduction

Several age-structured models have been developed and presented to the BSAI Plan Team since 2012. In 2019 four models were presented that had the following features:

- One fishery, one gear type, one season per year (single sex).
- External estimation of a single growth curve (vonBertalanffy) for length at age, weight at age.
- Internal estimation of fishing mortality, catchability, and selectivity parameters.
- All parameters constant over time except for recruitment and fishing mortality.
- Recruitment estimated as a mean with lognormally distributed deviations.
- An ageing error matrix for ages 1 through 10+.
- Logistic age-based selectivity for both the fishery and survey.
- Natural mortality was fixed in the base model using M=0.34 for consistency with previous Aleutian Islands Pacific cod assessments, and alternative M estimated with input from likelihood profiles performed using the model and other resources.
- Survey catchability estimated within the model as a constant multiplier on survey selectivity (fishery catchability fixed at 1).
- Maturity at age in the base model was estimated using observer data. This is consistent with the Gulf of Alaska Pacific cod assessment.

Five models are presented that examine sensitivity to natural mortality (M), maturity, and fishery selectivity (Table 1). In addition, the Tier 5 model is presented, which has been used for the AI cod assessment since 2013.

The data used in the models excluded fishery catch data from 1990, as the length frequency data included only summer onward, and contained relatively few records (1,140). Therefore, the first year of the models was 1991 rather than 1990.

Data Weighting

Data weighting for age composition data was important because there was some conflict between the survey biomass estimates and the age composition data. Higher age composition likelihood weights decreased survey catchability and reduced biomass estimates. Data weighting was performed on age composition data using the methods of McCallister and Ianelli (2007: Appendix 2, Equations 2.5 and 2.6). The weight factor for the age composition likelihood converged to 94 after 3 iterations. Statistical data weighting for fishery length likelihoods resulted in unreasonably high weights. The likelihood weight for fishery length composition data was set to 10 for all years, because it consists of lengths taken throughout the year from several gear types. Further exploration of data weighting will take place prior to the final model in November.

Model 19.0a Sensitivity to natural mortality

A value of 0.34 was used for the natural mortality rate *M* in all BSAI Pacific cod stock assessments from 2007 (Thompson et al. 2007) through 2015, and replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006 (Thompson et al. 2018). This value was based on Equation 7 of Jensen (1996) and an age at maturity of 4.9 years (Stark 2007). Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for *M* extends from about 0.30 to 0.38. In proposed models for 2021, EBS natural mortality ranges from 0.309 (Model 21.1) to 0.348 (Model 19.12a). For the Gulf of Alaska, a base natural mortality of 0.47 (SD = 0.41) was proposed for the 2021 model (Barbeaux et al. 2020).

A natural mortality estimate of 0.34 has used in the most recent Aleutian Islands Pacific cod assessment. In the 2016 Aleutian Islands Pacific cod assessment (Thompson and Palsson 2016), the authors recommended changing the value of *M* from 0.34 to 0.36, based on a new recommended model for the EBS Pacific cod stock (Thompson 2016).

A range of natural mortality values were explored using a likelihood profile on the Aleutian Islands cod model on natural mortality values from 0.1 to 0.9. The natural mortality likelihood profile showed some contrast in the results; the fishery length likelihood indicated that the lowest likelihood occurred at M = 0.3, whereas the other likelihood components (survey age, survey biomass, and recruitment) were minimized at M = 0.8. However, these likelihoods decreased quickly until M = 0.3 and remained shallow thereafter (Figure 1). The estimate for Aleutian Islands Pacific cod was 0.36 based on a tool for estimating natural mortality online (Figure 2). To balance the different likelihood components and consider the values for *M* used in other assessments, the value M = 0.4 was considered a good starting point. This value also represents the mode of previous estimates (Table 2).

The Plan Team and SSC have expressed concerns over the practice of equating the AI estimate of M with the EBS estimate (see comments BPT1 and SSC3); therefore we examine the use of a more suitable estimator. Therefore, the base model (Model 19.0) and Models 19.0b, 19.0c, and 19.0d, as well as the Tier 5 model used M = 0.34. Model 19.0a explored the use of M = 0.4.

Model 19.0b Sensitivity to maturity

The maturity-at-age is governed by the relationship:

$Maturity_{age} = \frac{1}{1+e^{-(A+B*age)}}$, where A and B are parameters in the relationship.

A study based on a collection of 129 female fish in February, 2003, from the Unimak Pass area, NMFS area 509, found that 50% of female fish become mature at approximately 4.88 years ($L_{50\%}$) and 58.0 cm, A = -4.7143, B = 0.9654 (i.e. Tables 2 and 4 in Stark 2007). This maturity ogive is used in the Bering Sea Pacific cod assessment but was not used in this assessment, because the fish in the sample were not from the Aleutian Islands.

An alternative maturity curve was developed based on observer records of maturity from the Aleutian Islands. This model may be advantageous because it is based on more records that were taken from Aleutian Islands cod, and this was used in the model presented here. Observers routinely collect maturity at length from Pacific cod. There are 2,098 records from the Aleutian Islands (Table 3) during the months January – March since 2008. These were used to estimate a maturity ogive by length using the R package *sizeMat*, which estimates the length of fish at gonad maturity. Maturity was considered a binomial response variable and variables were fitted to the logistic function above for maturity, and the length at which 50% of cod are mature is $L_{50\%} = -A/B$. The formula used to fit proportion mature by length was

$$Maturity_{length} = \frac{1}{1+e^{-(A+B*length)}},$$

and the resulting parameters were A = -7.882 and B = 0.1464. This ogive provided maturity at length which was converted to maturity at age using the length age conversion matrix, and was used in the assessment. The resulting ogive had $L_{50\%}$, slightly lower than the Stark (2007) estimate. $L_{50\%}$ was estimated to be 53.8 cm, age 4 (Figure 3, Table 4).

Model 19.0c Sensitivity to fishery length frequency data

Model 19.0c was not intended for an assessment, simply to consider how the models would change when the fishery length frequencies were not used. The fishery length frequencies are characterized by differences between cod caught during winter and non-winter months (Figure 4). Here, we define winter as January –April, which corresponds with spawn timing for Pacific cod in Alaska (Neidetcher et al. 2009).

Model 19.0d Two-fishery model

This model explores an Aleutian Islands age-structured model with two fisheries, a winter (January - April) and a non-winter fishery (May – December). This model aims to provide a more accurate selectivity curve for the two fisheries, as the winter fishery is characterized by larger, spawning fish, whereas the non-winter fishery consists of generally smaller fish (Figure 4). The model currently is not converging and testing is ongoing to determine whether there is sufficient data to support a two-fishery model.

Results

The four age-structured models produced similar fits to survey age frequency (Figure 5) and survey biomass estimates (Figure 6). Selectivity for the fishery and survey, as well as survey catchability, did differ among models (Figure 7). Model 19.0c indicated the highest survey catchability, while Model 19.0d the lowest. Models 19.0 and 19.0b had identical estimates of survey catchability and survey selectivity (Table 5). In all models, survey a50 was lower than fishery a50, which is reasonable as the survey catches smaller fish than the fishery (Figure 8).

Several statistical goodness of fit tests were used to examine the four models. The root mean squared deviation (RMSD) was calculated for biomass, and the fit to length and age composition data was measured using the square root of the sum of squared differences (SSD). The RMSD is a measure of the average difference between the observed and predicted total biomass of Pacific cod in the Aleutian Islands, and is similar to a standard deviation. The standard deviation of normalized residuals (SDNRs) was calculated for biomass data (Table 6). Model results did not differ significantly, but the CV of RMSD for biomass and SSD for fishery lengths were lowest under Model 19.0a. SDNR was not considered a diagnostic statistic, but values close to 1 are considered better, and plots of the fit to biomass are considered important diagnostic tools as well.

Likelihood components for the four models are shown in Table 7 for recruitment, survey age, survey biomass, catch, fishery length, and total likelihood. Likelihoods were similar regardless of maturity curve. The model with the lowest likelihood was Model 19.0a, with improvements primarily in the survey biomass and fishery lengths.

A retrospective analysis was performed extending back 10 years to evaluate Model 19.0, with data from 2011-2021. The value for Rho for Model 19.0 is -0.232. There are no guidelines regarding how large Rho (absolute value) should be before an assessment is declared to exhibit an important retrospective bias. However, -0.232 is in the range of values exhibited by many other Alaska groundfish species, and recent values for EBS Pacific cod were in the range of 0.4 and GOA cod were 0.3. The spawning biomass of Pacific cod has decreased and increased over the past 10 years and -0.232 represents an average in the differences between adjacent years. More retrospective analyses are in progress and will be presented at the September Plan Team meeting.

In addition to the four age-structured models presented here, the Tier 5 model is also a consideration for the 2021 AI Pacific cod assessment. As there is no new Aleutian Island survey data since the last full assessment, the Tier 5 reference points would not change from the 2020 assessment.

Tables

Table 1. Age structured models developed for Aleutian Islands Pacific cod, September 2021. In all models, 1990 fishery length frequencies and catch were excluded, and the modeled years were from 1991-2021.

Model name	Data changes from 2019	Model changes from 2019
Model 19.0	2019, 2020, 2021 catch and fishery length frequencies added	None. Base model with M=0.34, maturity ogive derived from observer collections of maturity values from Aleutian Islands cod.
Model 19.0a	2019, 2020, 2021 catch and fishery length frequencies added	Base model except M=0.40.
Model 19.0b	2019, 2020, 2021 catch and fishery length frequencies added	Base model except maturity defined as in Stark (2007).
Model 19.0c	None	Base model with no likelihood component for fishery lengths.
Model 19.0d	2019, 2020, 2021 catch and fishery length frequencies added	Base model with two fisheries, winter (January-April), non-winter

Table 2. Estimates of natural mortality, *M*, for Pacific cod throughout their range. Values marked with asterisks * have been used in stock assessments, and statistics are provided to summarize the estimates. The value mu represents the mean of the log values and sigma is the standard deviation.

Region	Reference Author	Year	M estimate
EBS*	Low	1974	0.375
EBS	Wespestad et al.	1982	0.700
EBS	Bakkala and Wespestad	1985	0.450
EBS	Thompson and Shimada	1990	0.290
EBS	Thompson and Methot	1993	0.370
EBS*	Shimada and Kimura	1994	0.960
EBS*	Shi et al.	2007	0.450
EBS	Thompson et al.	2007	0.340
EBS	Thompson	2016	0.360
GOA	Thompson and Zenger	1993	0.270
GOA	Thompson and Zenger	1995	0.500
GOA	Thompson et al.	2007	0.380
GOA*	Barbeaux et al.	2016	0.470
BC*	Ketchen	1964	0.595
BC*	Fournier	1983	0.650
Korea*	Jung et al.	2009	0.820
Japan*	Ueda et al.	2004	0.200

Statistic	Value
mu:	-0.6666309
sigma:	0.4929505
Arithmetic:	0.5797660
Geometric:	0.5134355
Harmonic:	0.4546938
Mode:	0.4026727
L95%:	0.1953790
U95%:	1.3492544

Table 3. Maturity at length records from Pacific cod from the Aleutian Islands during the months January – March since 2008.

Year	Number of records
2008	1185
2009	35
2010	156
2011	80
2012	151
2013	61
2014	128
2015	78
2016	79
2017	42
2018	26
2019	77

Table 4. Proportion mature by age, using Stark (2007) and observer maturity at length data.

Age	Stark 2007	Observer data
1	0.023	0.003
2	0.058	0.041
3	0.140	0.210
4	0.299	0.513
5	0.528	0.786
6	0.746	0.923
7	0.885	0.973
8	0.953	0.989
9	0.982	0.995
10	1.000	0.997

Table 5. Key parameters and the associated standard deviations from the four age-structured models: survey catchability (q), survey selectivity a50 parameter, survey selectivity slope parameter, fishery selectivity a50 parameter, fishery selectivity slope parameter.

Parameter	Model 19.0	Model 19.0a	Model 19.0b	Model 19.0c
Survey catchability	0.444 (0.039)	0.388 (0.038)	0.445 (0.039)	0.553 (0.096)
Survey a50	3.0809 (0.162)	3.2619 (0.160)	3.0809 (0.162)	3.463 (0.325)
Survey slope	1.2158 (0.094)	1.2283 (0.086)	1.2158 (0.094)	1.1061 (0.099)
Fishery a50	5.1701 (0.222)	5.2321 (0.225)	5.1701 (0.222)	4.9128 (0.512)
Fishery slope	1.7302 (0.209)	1.7473 (0.204)	1.7302 (0.209)	1.4789 (0.665)

Table 6. Goodness of fit tests for the four models, the coefficient of variation for the RMSD (root mean squared deviation) for fit to biomass, the square root of the sum of squared differences (SSD) for survey ages, and fishery lengths, the standard deviation of normalized residuals for biomass, as well as survey catchability estimated by the four models, Model 19.0, 19.0a, 19.0b, and 19.0c.

	Model 19.0	Model 19.0a	Model 19.0b	Model 19.0c
CV of RMSD for biomass	0.313	0.298	0.313	0.283
SSD for survey age	0.398	0.4	0.398	0.39
SSD for fishery lengths	0.26	0.259	0.26	0.304
SDNR	1.75	1.688	1.75	1.749

Table 7. Likelihood components for the age structured models four models under consideration.

	Model 19.0	Model 19.0a	Model 19.0b	Model 19.0c
Recruitment	5.685	5.270	5.685	5.846
Survey age	0.636	0.632	0.636	0.628
Survey biomass	16.041	14.330	16.041	13.608
Catch	0.001	0.001	0.001	0.001
Fishery Length	28.522	28.291	28.522	50.551
Total	50.886	48.524	50.886	70.634

Figures

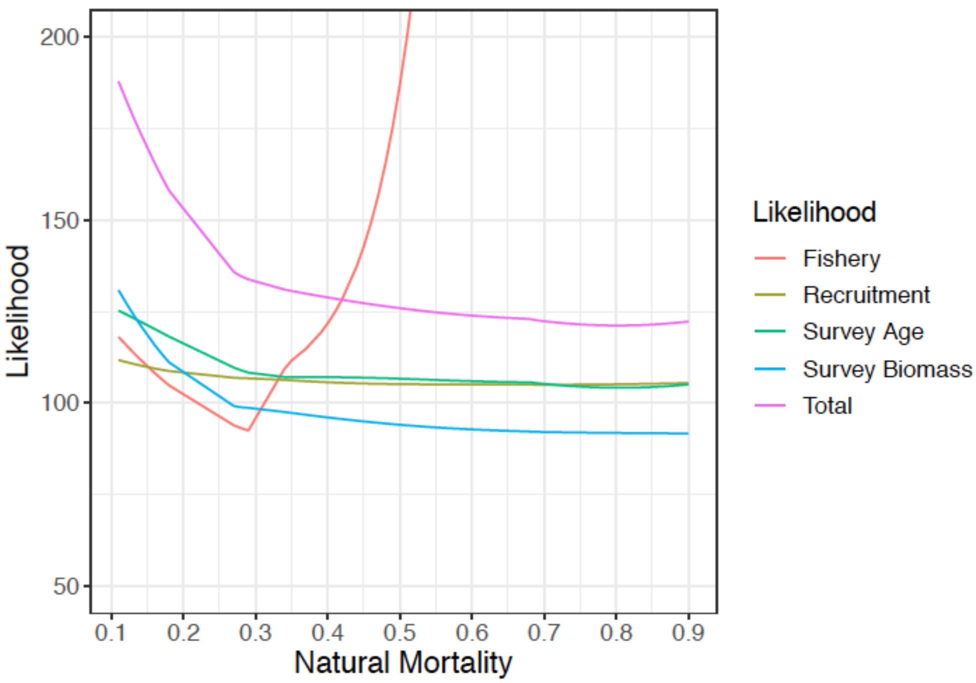

Figure 1. Likelihood profile for natural mortality for fishery length, recruitment, survey biomass, and age likelihood components.

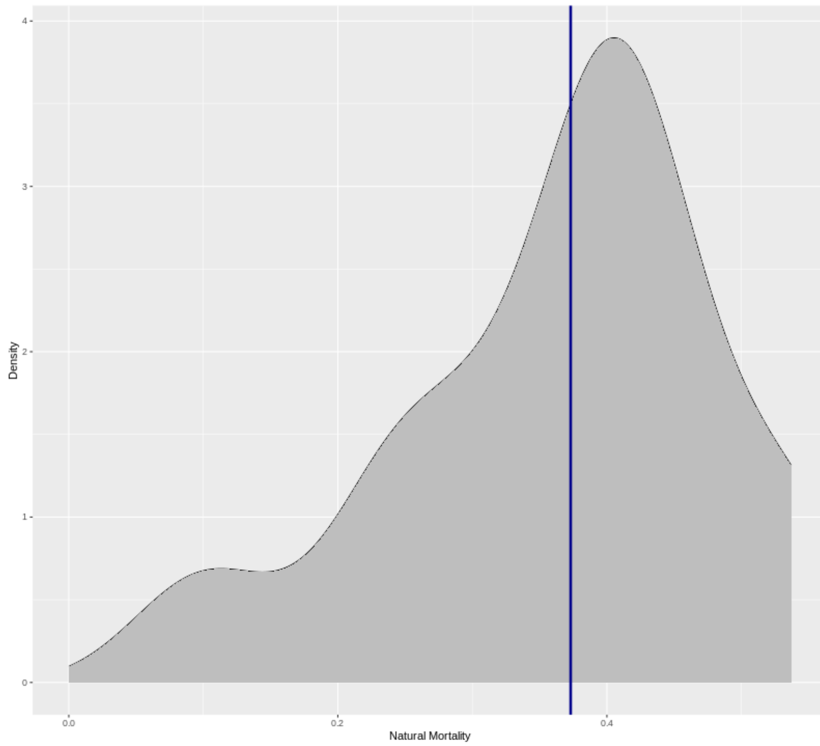

Figure 2. The estimate for Aleutian Islands Pacific cod was 0.36 based on a tool for estimating natural mortality online (http://barefootecologist.com.au/shiny_m.html) that uses life history parameters, and provides a composite estimate of M.

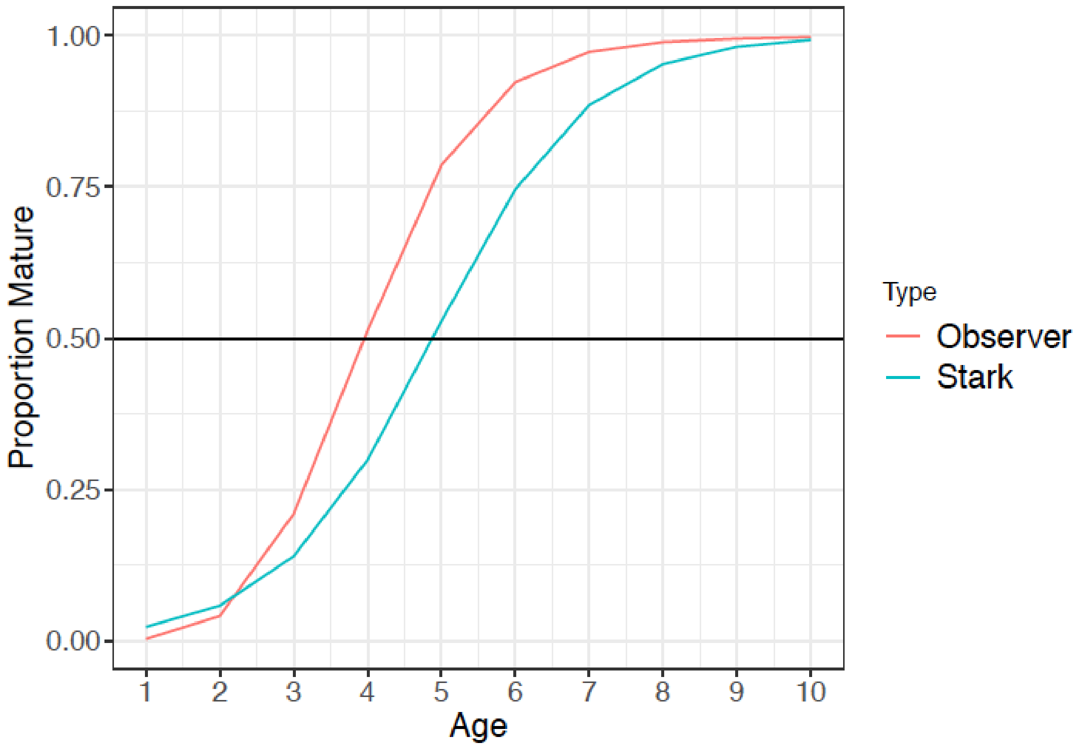

Figure 3. Proportion mature by age, using Stark (2007) and observer maturity at length data.

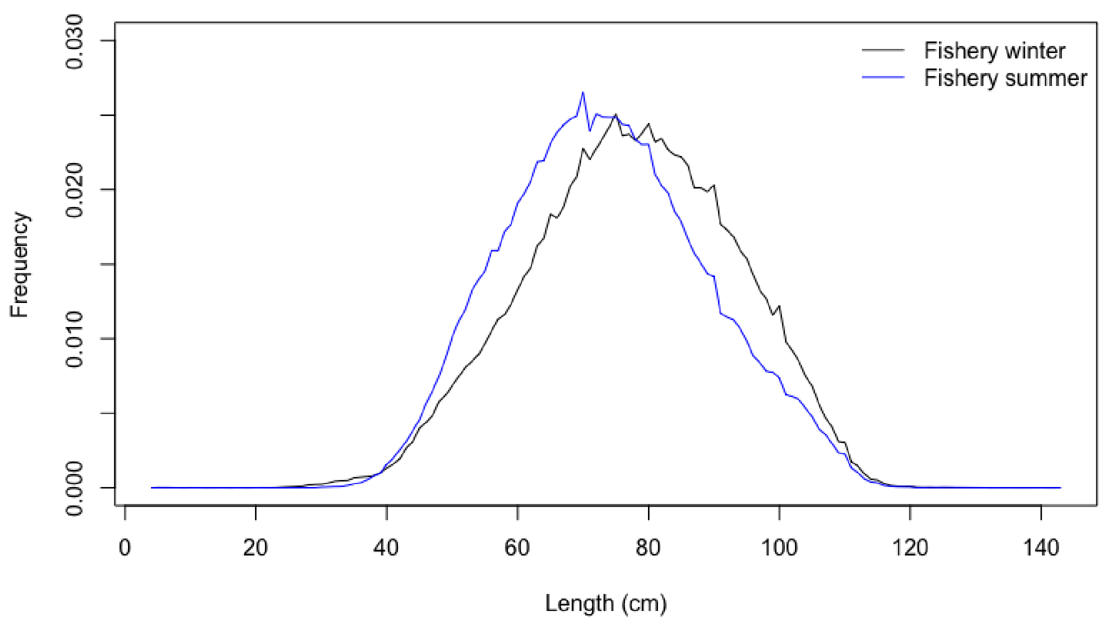

Figure 4. Length frequencies taken by Pacific cod fisheries observers from the Aleutian Islands (NMFS Areas 541, 542, 543) from 1991-2021. Winter is defined as January – April. Summer is defined as all seasons outside of winter (May – December).

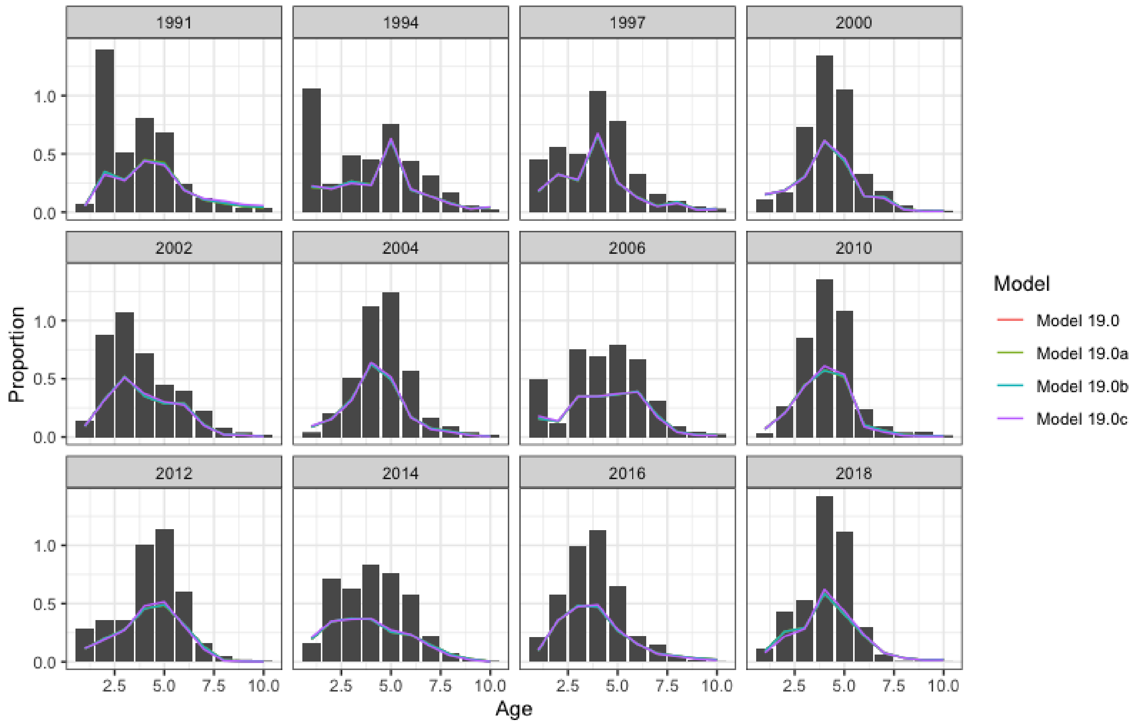

Figure 5. Survey age frequency fit to Model 19.0 (base model), Model 19.0a (base plus M = 0.4), Model 19.0b (base plus Stark 2007 maturity), Model 19.0c (base minus fishery length frequency likelihood).

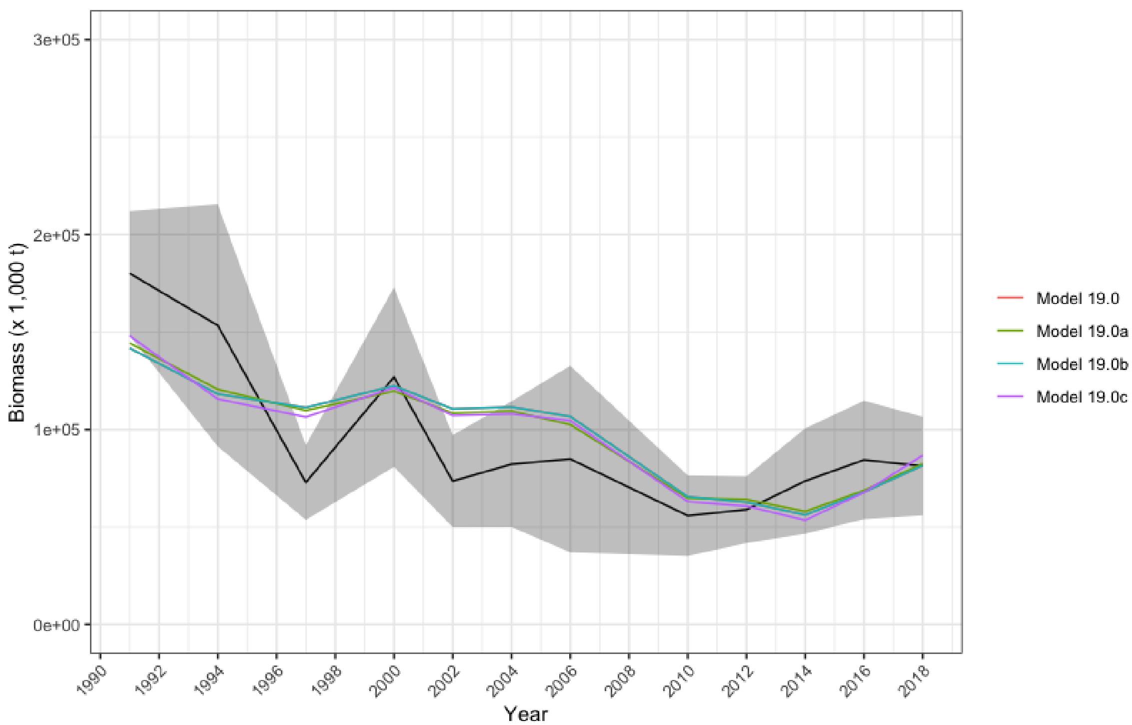

Figure 6. Aleutian Islands survey biomass estimates, from 1991-2018, with 95% confidence intervals and four model estimates of survey biomass, scaled by survey catchability: Model 19.0 (base model), Model 19.0a (base plus *M* = 0.4), Model 19.0b (base plus Stark 2007 maturity), Model 19.0c (base minus fishery length frequency likelihood).

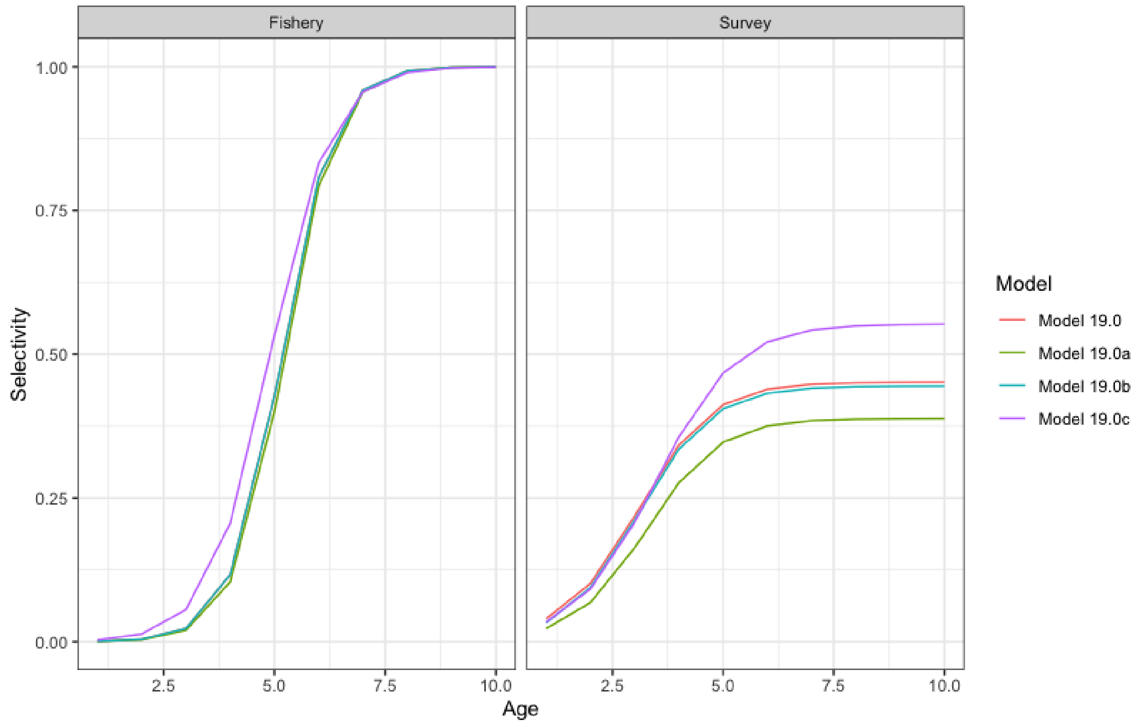

Figure 7. Model estimates of selectivity for the survey and the fishery. The survey selectivity curve is the product of survey catchability and survey selectivity. Note: Model 19.0 and Model 19.0b survey estimates have identical values.

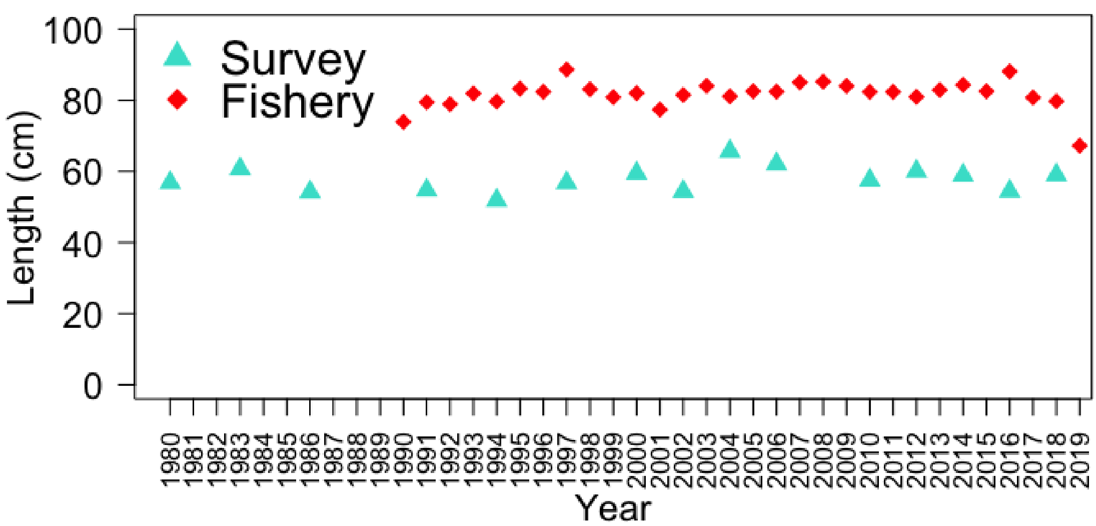

Figure 8. Average length frequencies of fish caught in the survey vs. fishery, 1980-2019.

References

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